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Environmental and health risk evaluation on basis of fuzzy concept around Gyöngyösoroszi

Thesis of the Ph.D. studies

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Introduction and Preliminaries

The practical realization of the theory of the theory of the maintaining development is the interest of all of us, as well as maintenance of our health, as to protect the environmental elements. Having joined to the European Union the Hungarian policy of environment is involving the policy and orders of the environmental protection of the developed countries into its legislation. On basis of the developed limit-value system (Joint Departmental Order No. 10/2000. (VI.2. KÖM-EÜM-FVM-KHVM) the Hungarian environmental policy built on the risk assessment on the vulnerable areas, than depending on the results of environmental and health risk evaluation for the planning and implementation of the remediation (Filep Gy. Et al., 2002). In course of this usually traditional method of mathematics were applied for estimation and for the decisions as well (Dura Gy. et al., 2001; Gondi F. et al., 2004) that often could not be applied due to the quality and quantity of the data available or due to the characteristics of the studied area. In such a case a more flexible mathematic access is required, which can be possible by the fuzzy concept.

The appearance, built in the philosophy of the fuzzy aspect, later in the mathematics (Zadeh L. A., 1965) as well, brought great rate in solving problems that could not handle with traditional probability methods. In the 20th century it has been applied in the field of economics, informatics than as well as in the classic natural sciences. Theory of multivalent sets of many values based on the classic probability calculation and strict mathematic regulations, that is the fuzzy logics enables the realistic systemizing, interpretation and handling of the elements of natural systems and of those being conform with the characteristics of the measured values and their values. It is easier to take into consideration the examined elements, and to express the uncertainty connected and the compound decision processes and to solve the divergent calculation of the natural processes. On the fuzzy-numbers got by applying the logistic regression the calculation operation required for the examination of specific scientific fields, for the evaluation of the same with different defuzzyfication processes the fuzzy numbers can be reformed into crisp numbers (Kóczy T. L. & Tikk D., 2001).

Having utilized this advantageous characteristics it can be applied in the risk evaluation processes as well, where adequate information are not available as their quality and quantity concerning the environmental element or pollution. The advantage of the fuzzy method is that the very necessary information can be treated in the calculation in linguistic variable forms as well, thereby making the picture more precisely about the studied area, the targets and the exact information of the potential pollution.

In my study I am dealing with the heavy metal pollution around Gyöngyösoroszi, with the environmental and health risk of the arsenic, cadmium, copper, lead and zinc. This area is a special one, because it can be characterized with natural geochemical anomalies, that due to the human

surface-deforming activity – first of all the mining – and as an effect of its consequences it has been formed further on from point of view of the risk assessment it has meant a challenge for many reason. On one hand because of the important natural background it is of outstanding importance to learn the environmental and human health risk, on the other hand the human activity further manages the extension of the natural anomalies. By this the application of the traditional methods is becoming questionable.

Among the five examined elements the arsenic causes usually the greatest hazard for the ecosystem: beside the high toxicity it has significant carcinogenic effect as well. Cadmium and lead are toxic heavy metals as well, at the same time zinc and copper are essential trace elements for the plants, for animals and for the human organism as well. In case of an excessive intake even the essential trace elements can cause adverse effects in the living organism depending on the interaction of the different biochemical processes.(NAS, 1986; JECFA, 1993; US EPA, 2006)

In the period 2001-2002 I had the possibility to take part in an international summer course organized by Katalin Gruiz, that was dealing with the measuring of the heavy metal pollution around Gyöngyösoroszi. After the field-work of the course I took samples on the inhabited area, beside these data I took into consideration literary values of samples collected by other institutions and organs as well.

Purposes

One of the basic goal of my study is to estimate the environmental and human health risk of the heavy metal pollution around Gyöngyösoroszi, the other was to introduce the fuzzy concept into the risk assessment. In this connection the following detailes targets determined my research on the area examined:

- summarize and comparison of the basic definitions relating the risk determined in the international and Hungarian scientific literature;
- formulation of the position and role of the risk-analyze and risk-estimation in the hierarchic system of the risk assessment;
- presentation of international treaties, policies and organs concerning the change of the Hungarian environmental policy and risk estimation;
- comparison of risk estimation methods on basis of literary and area-specific data;
- emphasis of the necessity of site-specific risk-estimation – first of all for areas characterized by significant heterogeneity and high natural background concentration;
- to involve the immeasurable parameters into the site-specific risk evaluation;
- to demonstrate the uncertainty of the parameters involved in the calculation;

- to show the application possibilities of the fuzzy concept that offers a flexible method in the environmental and health risk evaluation;
- to collect the former research data of the studied area, application, evaluation and supplementation of the data;
- determination of the site-specific characteristics of the hazard parameters and the comparison of the same with data of the scientifical literature;
- determination of the pathways leading to those suffering the effects and through certain factors to determine the exposition on the studied area and to emphasize the adverse effects and the consequences;
- to collect the toxicological data of studied pollution and to explain their behavior in the environmental elements on the studied area;
- comparison of the results of the site-specific fuzzy method with the value received by the former traditional methods of literary and site-specific risk evaluation (Sipter E., 2008).

Methods on the pilot areas

During the past two decades the research work in order to study the heavy metal pollution (Dura Gy. et al., 1988; Záray G., 1991; Bekő J. et al., 1992; Záray Gy. et al.,1992; Lonsták L. & Józsa G., 1992; Halmóczki Sz., 1993; Marth P. et al., 1994; Váncsa A-né, 1996; Fügewdi U. & Horváth I., 1997; Ferwagner A., 2002; Fügedi U., 2004, 2006; Lázár B., 2004; Ötvös K. et al., 2004; Gruiz K. et al., 2007; Németh G. et al., 2008; Sipter E., 2008) applied different sampling, preparation and analytical processes for the different sampling points on basis of different hypotesis. For the natural and artificial variability I applied the fuzzy concept (Zadeh, L. A., 1978).

In Gyönygyösoroszi according to the Hungarian Standard No. MSZ 21470-50 (1998) I collected soil and plants samples with Sipter. The concentration of arsenic, cadmium, copper, lead and zinc were determined with aqua regia advised by US EPA (1994) and it was determined with inductive plasma mass spectroscopy (ICP MS). First I examined the concentration data with traditional geostatistical methods, than with literary data taking from the same soil depth with similar chemical analysis (Ferwagner A., 2002; Ötvös K. et al., 2004; Gruiz K. et al., 2007; Németh G. et al., 2008) together with the fuzzy concept I developed. With help of questionnaires together with Sipter I measured the state of health and nourishment habits of social groups in 2001-2002. I compared the data with the values contained in the literary databasis (JECFA, 1993; US EPA, 1997a) and I also used the data of the examination of state of health made in 1987-88 (Dura Gy. et al.1988):

According to the extension of the flooded area I selected four groups with clasteranalysis, and according to the fuzzy concept with normalizing and weighting of the concentration values of the five studied elements I selected seven groups (Mérő L., 1989). I used the geostatistical methods

with Statistica 8.0 and the steps of the fuzzy concept with Excel 2003 and Grapher program. I converted the coordinates of the State and Budapest Stereo of the boring with 3.22 Version of the Projection (Völgyesi L. et. Al., 1992) and to design the maps I used Surpher Version 8.

Beside the traditional geostatistical examinations – because of heterogeneity in time and space – I applied fuzzy concept for the data analysis and calculation.

For the ecological risk assessment beside the site-specific characteristics and heavy metal pollution of soil I included the literary data of the cultivated plants and the plants growing wild collected on this area and the literary data of animal organisms of lower species and those of higher species.

In the background of the uncertainty studying the natural systems the error coming from the natural variability and in connection with the possibility to compare the collected data, and the uncertainty (Fodor J. & Robins, M., 1994; Bárdossy Gy. et al., 2000; Bárdossy Gy. & Fodor J., 2004). In case of the data coming from the Gyöngyösoroszi area all the three factors are significant and in addition the heterogeneity of anthropogenic origin from the effects of the mining, and the heterogeneity and error coming from the different methods of the sampling. As a result of the research made until now the proved background concentration (Ab) (Fügedi U., 2006) and the determination of certain remediation contamination limit value concerning the Northern- the Middle and the Southern parts of the studied area (Environvest Kft., 2006a,b, 2007).

For the risk evaluation I used the databasis NAS (1986), JECFA (1993) and US EPA IRIS (2006). I compared the bioconcentration factors with the data of the literature dealing with soil-plants system (Kabata-Pendias, A. & Kabata, H., 1984; Csatho P., 1994). The toxicity data of the animals of higher species were based on the veterinary and feed toxicological literature (Laczay P., 1995; Mézes M., 1997), the intake values were taken from the feeding literature (Schmidt J., 1996). I applied the equations of the calculations on basis of the US EPA (1993, 1997) and for the advice of Albering, H. J. and colleagues (1999). I compared the fuzzy numbers I got as a result with the former, traditional and site-specific risk evaluation (Sipter E., 2008).

Theses

The specific significance of the results involved in my study can be summarized as follows:

1. The heavy metal pollution around Gyöngyösoroszi means exposition for the environmental elements and for the organism of the inhabitants under specific natural and artificial conditions. In the natural heterogenity of data the different phase of the mineralization play significant role and the extension of the frequent and sudden flood of creek coming from the mining area. On basis of the border of the area flooded in 1996 with traditional geostatistical method four groups and according to the appearing of the studied five elements all with fuzzy concept seven groups

can be identified being characterized with increasing pollution on the inhabited territory. With fuzzy method I could separate seven groups on the mining territory as well, though these were formed less equally due to the antropogen effects than those on the inhabited territory. These groups due to their different characteristics are equally justified to be taken into consideration with different fuzzy numbers in the environmental and health risk evaluation.

2. The factor analysis of the soil samples of inhabited areas refers to two striking different factors on basis of the concentration values of the five studied elements. The first factor refers for the mineralization of Pb-Zn-Cd(-Cu) of middle temperature, while the second one refers to the later mineralization of As(-Hg-Cu) of lower temperature. The further examination of this latter one would be justified on the mining territory.
3. On the volcanic minerals resulting natural heavy metal anomalies due to the high clay-content only a smaller rate of the heavy metals are accessible for the living organisms of plants and animals. This rate is expressed by the bioconcentration factor (BCF), the space-specific value of which is significantly different on the territory of Gyöngyösoroszi as that of the literary data, first of all in case of arsenic considered as the most toxic one (the literary 0,05, on the site-specific median on inhabited territory: 0,00035, on the mining territory: 0,018). Therefore in the environmental and in the health risk assessment a wrong result can be given by using the literary BCF values. Therefore in case of site-specific risk assessment it is necessary to determine the representative site-specific BCF value for more species of plants and animals that is enabled only by a great number of samples carefully collected due to the effects of the physical, geo- and biochemical processes going on in the studied environmental elements.
4. Weighting on basis of the Hungarian limit value (B) that neglects the natural anomalies can give wrong result in the environmental risk assessment too for a territory having special characteristics. In case of Gyöngyösoroszi on inhabited territory the proved background concentration (Ab) and on the remediation pollution limit value (D) is justified in the weighting as the natural background concentration (B) is manifold of the pollution limitvalue (As: by 2,33, Cd: by 2,5, Cu: by 1,78, Pb:by 2,86, Zn: by 2,5).
5. For the ecological risk evaluation I got the representative weight factors having taken into consideration the site-specific BCF values of the living organisms at the soil and at the plant samples the BCF values of the earthworms that helps to take up the heavy metal content (Kabata-Pendias, A. & Pendias, H., 1984; Kádár I., 1998) on inhabited and mining territory as well. At consideration of the weight factors received for the species each or only considering the toxicological values I got a manifolded weight value once for one element and another time for another element. For the determination of the BCF value of the earthworm the site-specific data would be the most conform, for this however more sampling would be required. Lacking this I

looked for data in the literature dealing with the pathway of soil-plant in order to receive the medians of the concentration measured in the soil. In this iteration step the value of the risk index counted for plants remains under the limit of acceptability it shows moderate risk.

6. The ecological risk of the moufflons being sensitive for copper and zinc, the plant intake of the smaller sheep and on basis of the veterinary toxicological data refer to a lower, negligible risk. However in this iteration step I have not taken into account the heavy metal content of the adhesive soil particle to the plants and that of the water of creeks and wells among the pathways, for this further examinations would have been required for the moufflons as their site and specie specific, though the negligible risk index does not justify this examination.
7. For the risk evalation of the inhabitants of Gyöngyösoroszi it is justified to involve the data of questionnaires made together with Sipter, as the gardening and the way of nourishment are different as those in the literature. Due to the disadvantageous hygienic circumstances of the inhabitants it is one of the measurable parameter, the quantity of soil particles intake that is different from data of the literature, and this is what I could take into consideration with fuzzy concept. I based this upon the questionnaires.
8. On basis of the assessment of parameter for the measurable and immeasurable risk parameter of the groups suffering this effect I combined fuzzy numbers and I involved these into the site-specific estimation. In this iteration step I got a great risk index approaching the limit of the acceptability for children, women and men as well. The three results are very near to each other, however in case of women it is the smallest and the biggest for men who had worked in the mines before.
9. Because of the reasons mentioned above the use of data being uncertain and handling the uncertainty can be implemented by the fuzzy concept only with the available data that is normalized with logistic regression and weighted with considering the characteristics of the studied parameters. The result we got like this made the evaluation of the traditional literary and site-specific data more accurate as at all the three groups under risk I could take into consideration the accumulating uncertainity of each risk parameter and with fuzzy concept more plant species' data could be included. On basis of this we can evaluate the probable risk of the state of health, the way of nourishment and the individual sensitiveness and inclination on a given level.
10. The basic concept used in the Hungarian scientific literature for risk assessment do not follow the definitions determined by the international organs in each case, therefore it is justified to make it more exact. The concept of risk is complex, because in addition to the probability of an adverse event and its heaviness it contains its frequency for a given period of time and for other

unit too. The EC_{50} used in the toxicology can refer not only for the adverse effects, but for any beneficial effect of any medicine or material considered as drug.

11. For making exact the results of the environmental risk assessment we have to minimalize the data of the literature, that we can promote with sampling according to the standards and involving the data reflecting the space specific data of risk parameters. This is justified first of all on territories of outstanding heterogenity and special characteristics.
12. From point of view of the traditional mathematical methods the involving of immeasurable parameter in linguistic variables can make the risk more exact, if they reflect the characteristics of the studied area, pathways or characteristics, which would influence the result of assessment if neglected. This can be implemented with help of fuzzy risk evaluation.
13. In case of linguistic variables the triangular or trapezoid fuzzy numbers can be determined for the risk parameters. To normalize the values of significant uncertainty, using the logistic regression, and with carefully chosen weight factors seven fuzzy groups should be separated.
14. In course of the composition process in case of more studied parameter the seven groups should be formed with taking into consideration these all together. The core of the fuzzy numbers of each groups means the sample that the smallest difference has comparing to the group of the less and greatest contamination considering its normalized and weightened values, at the same time in its own group it has the highest value.
15. At the evaluation of the site-specific health risk the measure of the intake of the studied pollution in plants is determined first of all by the planting circumstances on the site of the exposed inhabitants. This can be made with questionnaires, data of which can differ from those of the data of literature and this can influence the result of the evaluation in case of the Hungarian inhabitant.

Conclusion

Around Gyöngyösoroszi in the soil and in the plant species higher heavy metal concentration can be measured than allowable however therefore on the higher trofic levels the measure of the ecological risk is gradually reduced. All this refers to the fact that due to their outward form the heavy metals in the soil are difficult to access for the living organisms though depending on the physical, chemical and biochemical characteristics from the microbial in soil organisms and also depending on the specie-specific bioconcentration factor of the given plant certain plants can locally easier building these into their organism. Among the agricultural plants the horse radish can take up As, Cd and Zn, tomato can As, Cd and Cu, parsley and sorrel can Cu, Pb and Zn in significant quantity. The further study of the soil and site-specific BCF is justified around Gyöngyösoroszi.

The ecological risk determined on basis of the soil and plant samples taken on the inhabited and mining areas was less than expected in case of the plants and the moufflon as well while the health risk index counted for the eating of the locally produced plants is unacceptable. To make it more exact and the consideration of their intake with other foodstuff must be in the next iteration step. As a whole I did my best to make a complex risk evaluation for the sample area, which can be a starting point – I hope due to the problem-exploring attitude on this territory and also in areas contaminated by heavy metals for further site-specific risk assessment processes. The calculation made are in accordance with the second rate ecological and health risk evaluation of the heavy metal contamination around Gyöngyösoroszi.

In the environmental and health risk evaluation of other territories having significant uncertainty the calculation method of fuzzy concept I developed is identically advisable where it is always required to carefully determine the weight factors flexibly adjusting to the characteristics of the pollution on the given territory.

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